Heavy Ion Current Transients in SiGe HBTs

Jonathan A. Pellish[1], R. A. Reed[2], G. Vizkelethy[3], D. McMorrow[4], V. Ferlet-Cavrois[5], J. Baggio[5], P. Paillet[5], O. Duhamel[5], S. D. Phillips[6], A. K. Sutton[6], R. M. Diestelhorst[6], J. D. Cressler[6], P. E. Dodd[3], M. L. Alles[2], R. D. Schrimpf[2], P. W. Marshall[7], and K. A. LaBel[1]

[1]: Radiation Effects and Analysis Group, NASA/GSFC Code 561.4, Greenbelt, MD 20771

[2]: Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN 37235

[3]: Sandia National Laboratories, Albuquerque, NM 87175

[4]: Naval Research Laboratory, Washington, DC 20375

[5]: The CEA, DAM, DIF, F-91297 Arpajon, France

[6]:School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332

[7]: NASA Consultant, Brookneal, VA 25428

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04 94AL85000.

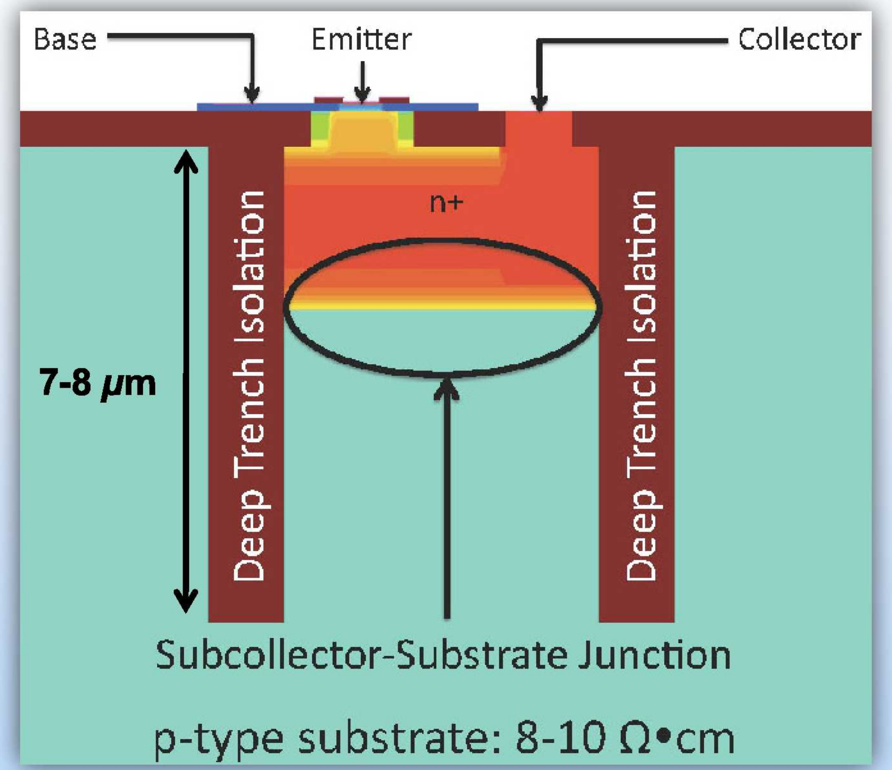
Overview

- Look at device under test (IBM 5AM SiGe HBT)
- Review bias conditions of interest
  - Relation to findings of previous experiments
- Heavy ion microbeam data
  - 36 MeV ^{16}O (SNL)
- Heavy ion broadbeam data
  - Low- and high-energy tunes (JYFL and GANIL)
- Path forward and summary

Device Background and Introduction

- **Key device characteristics**
  - **Deep trench isolation**
  - **Subcollector junction**
  - **Lightly-doped p-type substrate (large)**
- **Extend state-of-the-art knowledge**
  - **Move beyond charge collection**

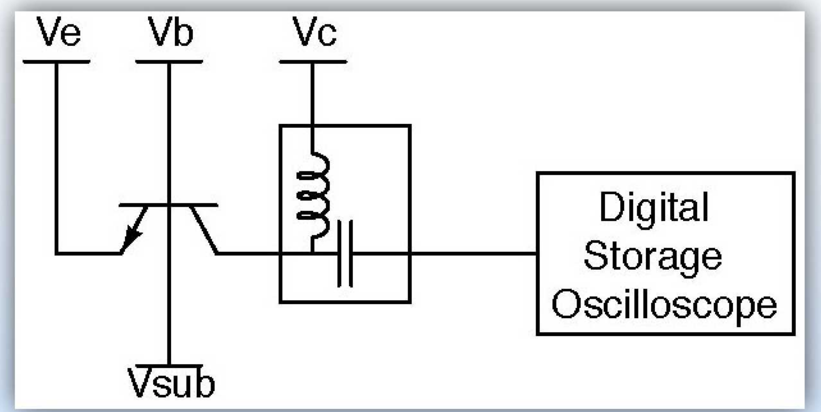
IBM 5AM SiGe HBT (0.5 *μ*m)



J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

Previous measurements on SiGe HBTs have only looked at laser-induced transients or heavy ion charge collection.

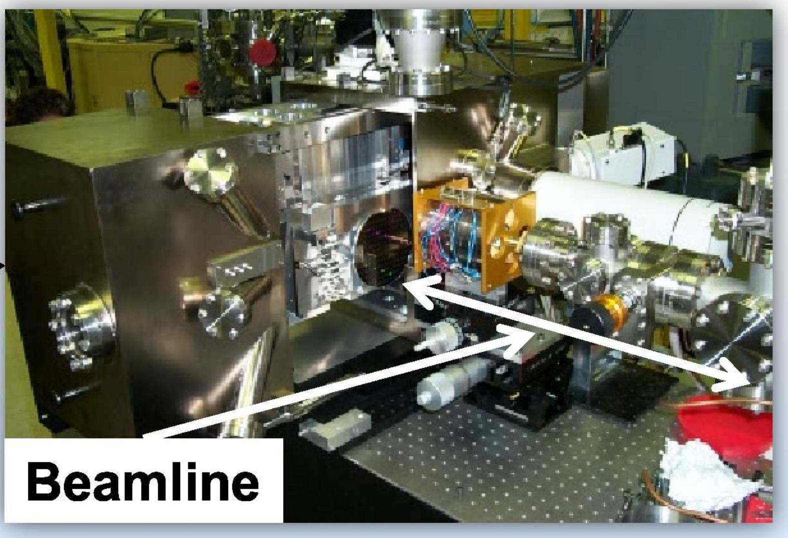
Microbeam Experimental Setup

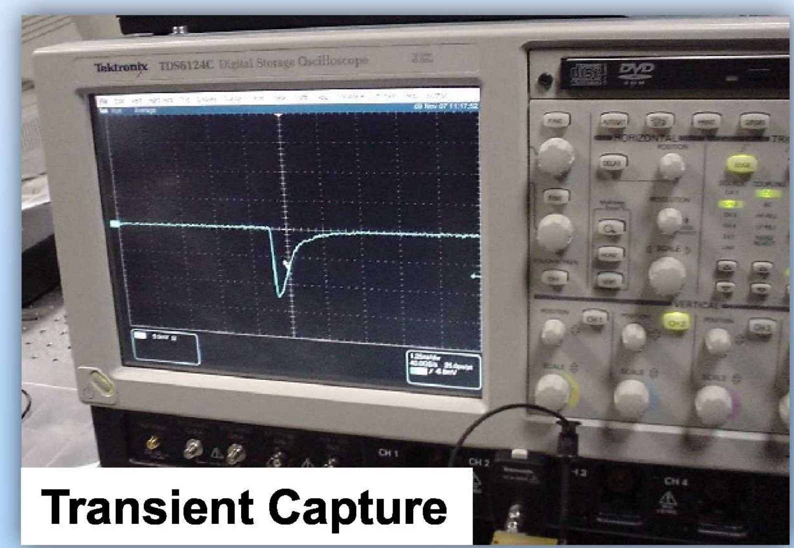


Similar setup for 4-terminal measurements

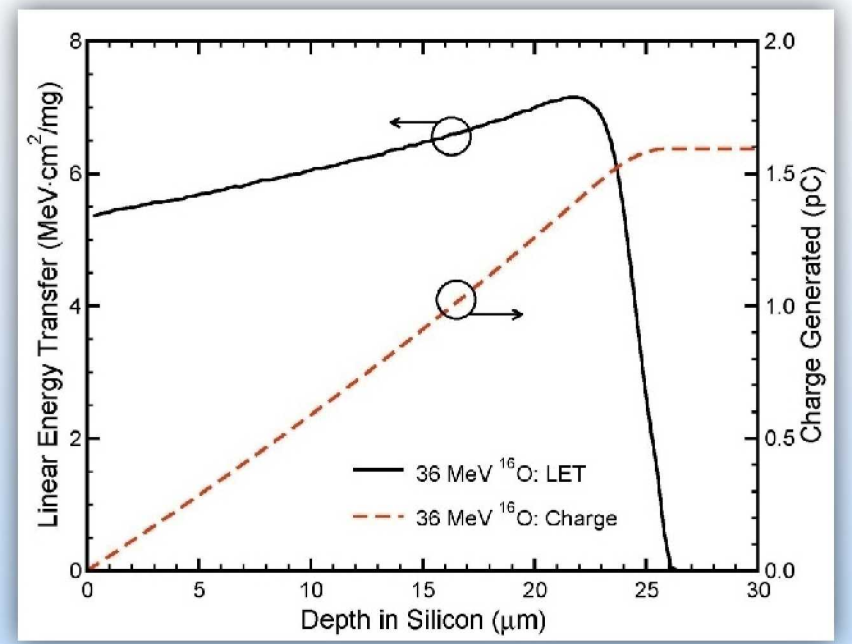
- **PSPL Bias Tees: 5542K**
- **DPO/DSO: Tek 71604A (16 GHz; 50 GS/s), Tek 72004A (20 GHz; 50 GS/s)**
- **2.9 mm coaxial cable assemblies (40 GHz)**

Sandia National Laboratories' Microbeam Chamber





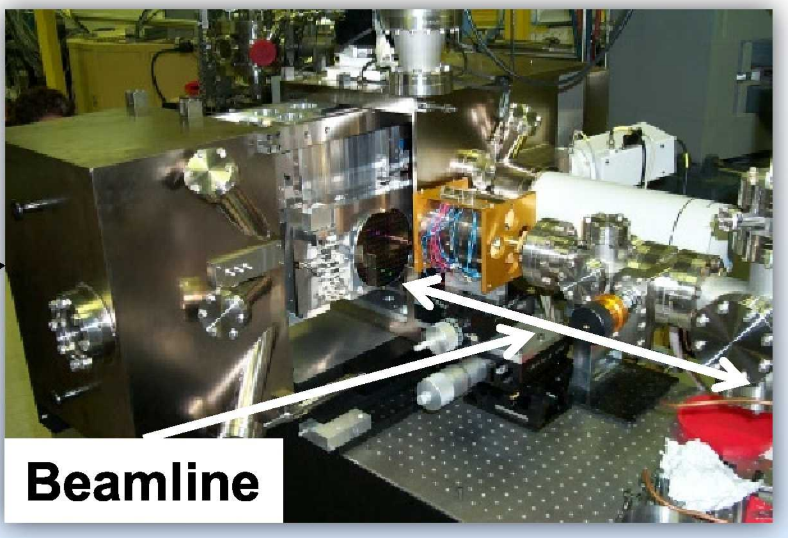
Microbeam Experimental Setup

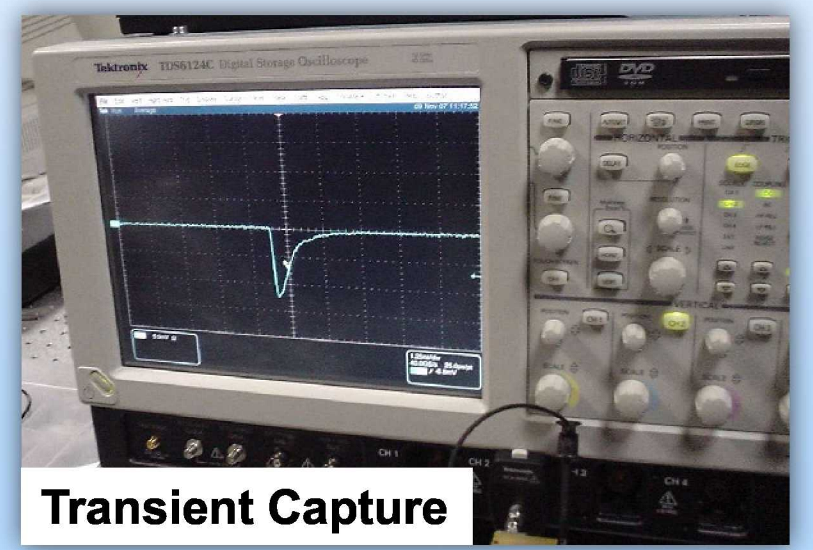


36 MeV ^{16}O d*E*/d*x* profile

[SRIM-2008]

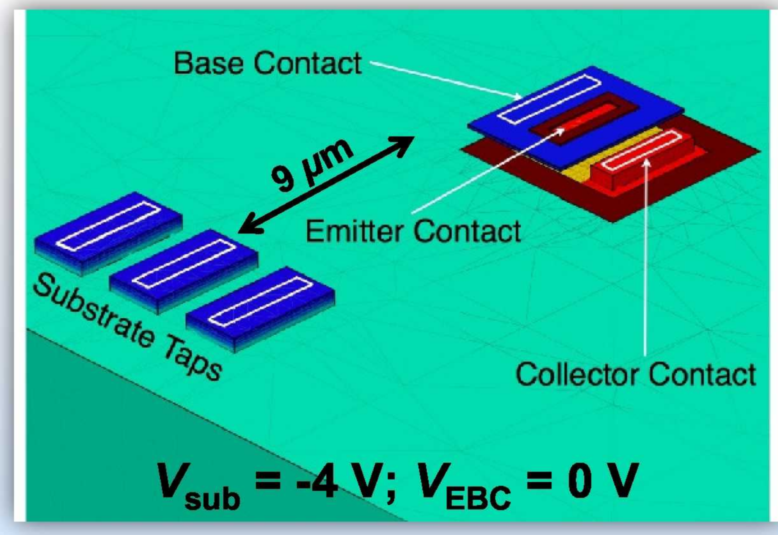
Sandia National Laboratories' Microbeam Chamber



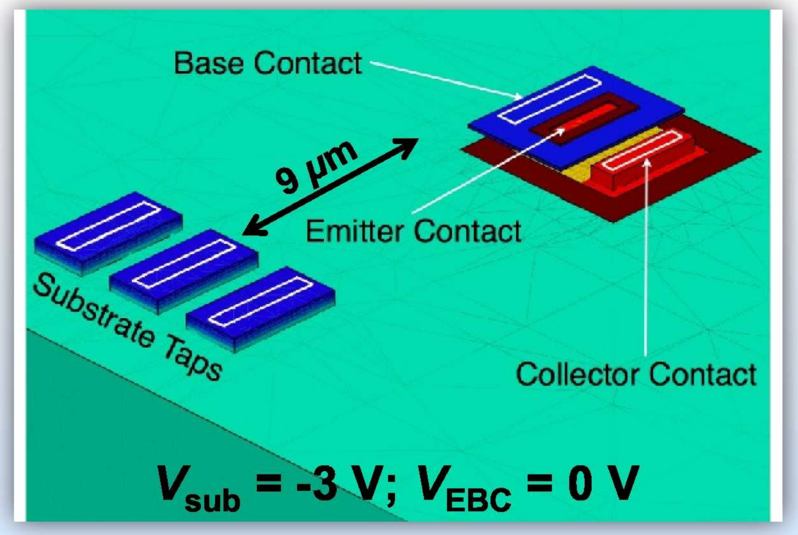


Bias Conditions of Interest

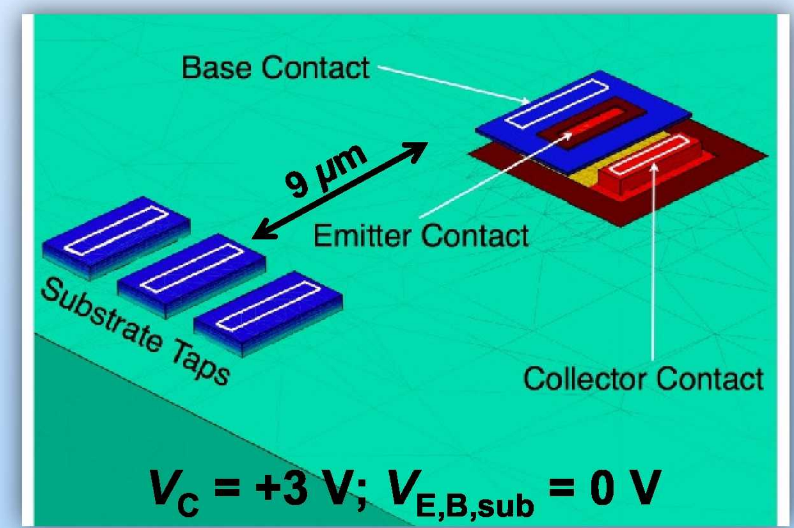
CASE 1



CASE 3



CASE 2

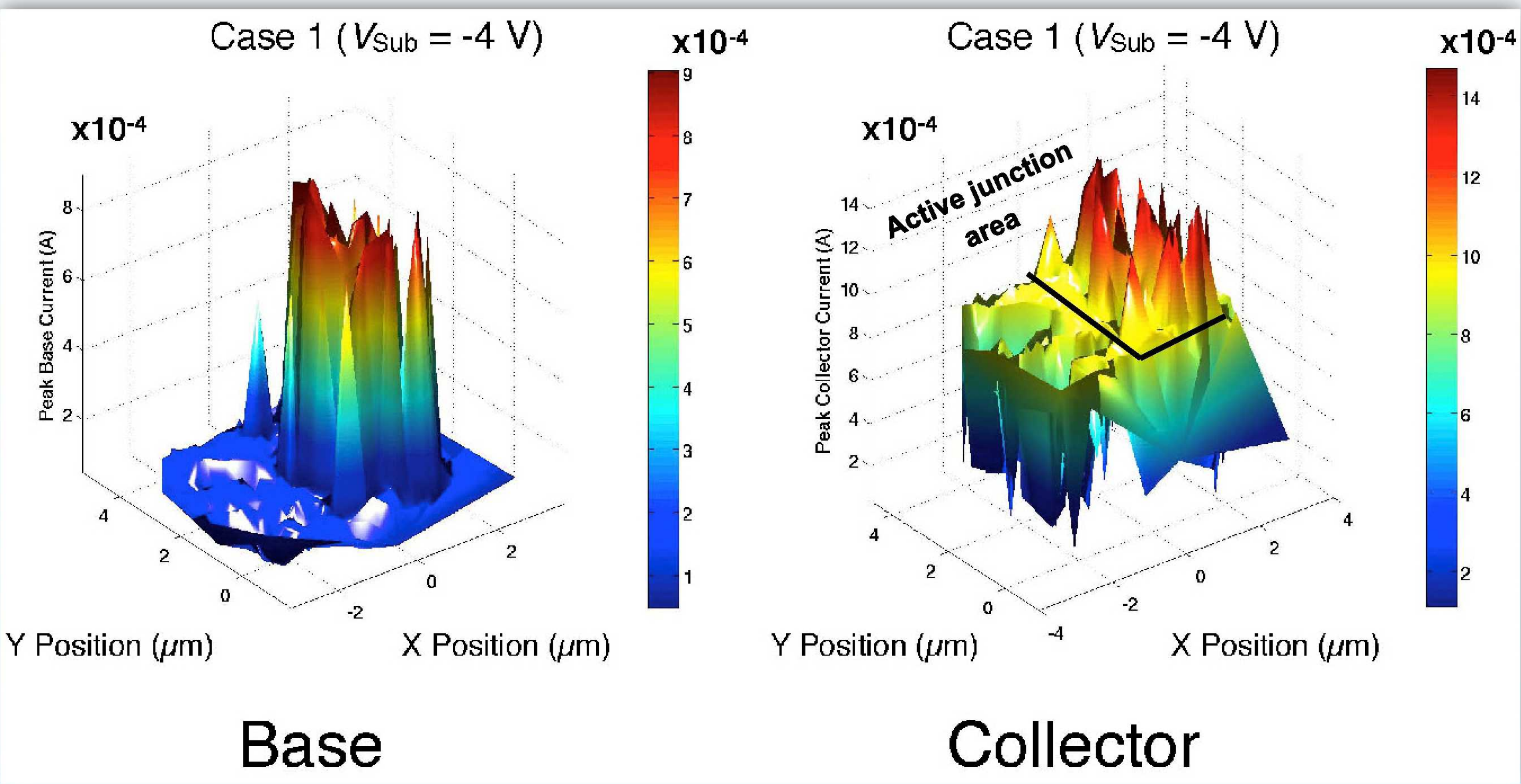


- 3-D TCAD
- Rendering from GDSII of actual DUTs

To be presented by Jonathan A. Pellish at the 18th Annual Single-Event Effects Symposium (SEE Symposium)
La Jolla, CA, 20-22 April, 2009 and published on http://radhome.gsfc.nasa.gov/ and http://www.nepp.gov/.

36 MeV ^{36}O Microbeam Data: Case 1

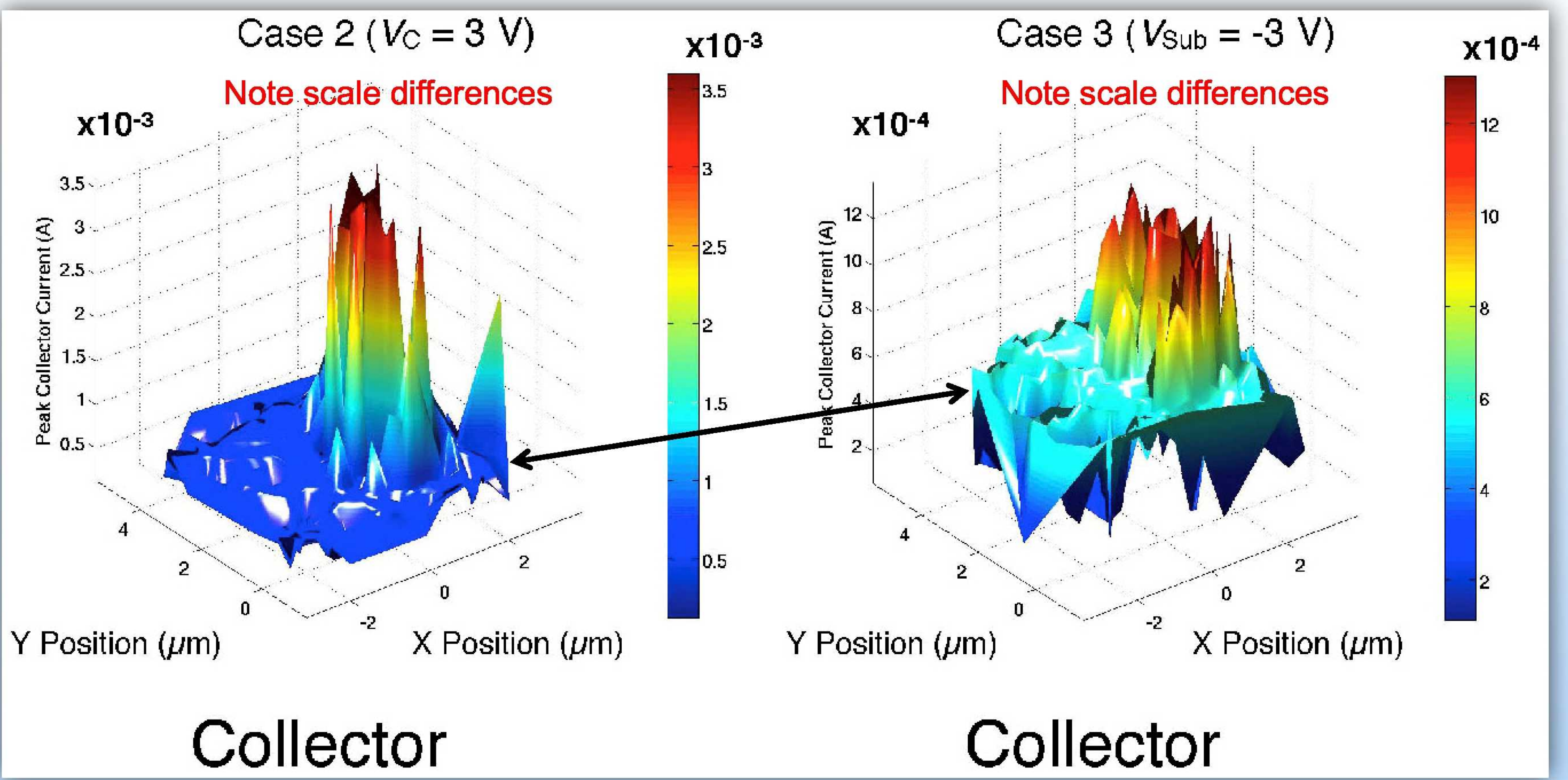
Peak Current Magnitude



- Base terminal images base-collector junction
- Collector terminal images base-collector junction and subcollector

36 MeV ^{36}O Microbeam Data: Cases 2 & 3

Peak Current Magnitude

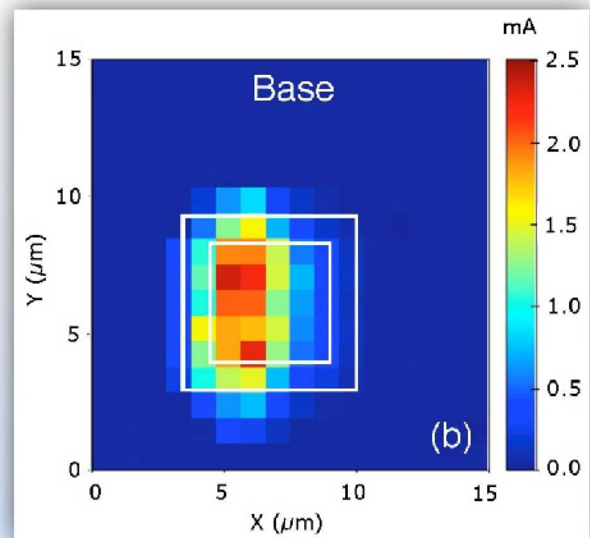


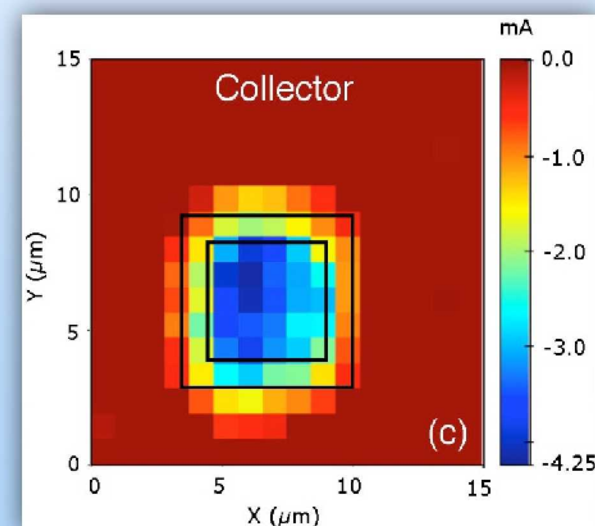
- Significant current magnitude increase for V_C = +3 V
- Observed in two-photon pulsed laser testing too

To be presented by Jonathan A. Pellish at the 18th Annual Single-Event Effects Symposium (SEE Symposium)
La Jolla, CA, 20-22 April, 2009 and published on http://radhome.gsfc.nasa.gov/ and http://www.nepp.gov/.

TPA Pulsed Laser *vs.* Microbeam

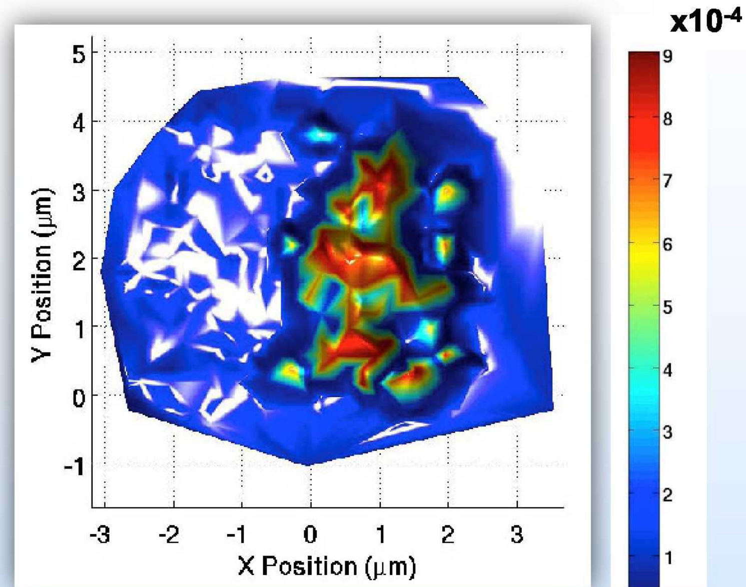
J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

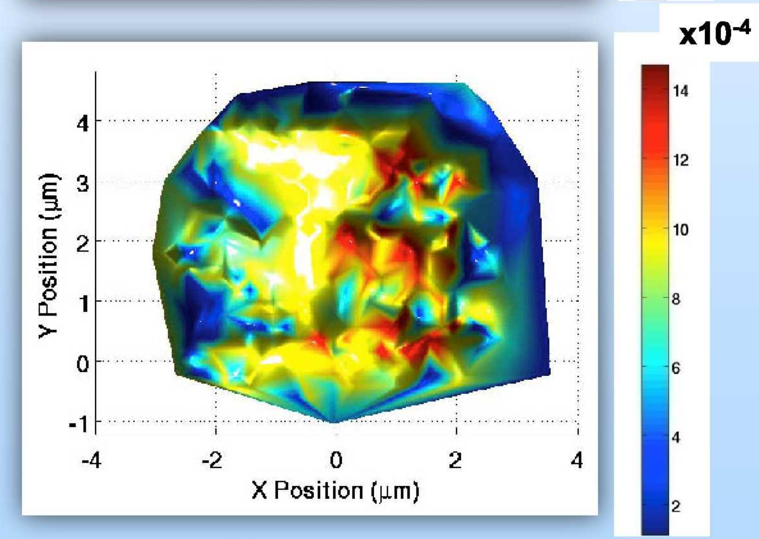




TPA Pulsed Laser

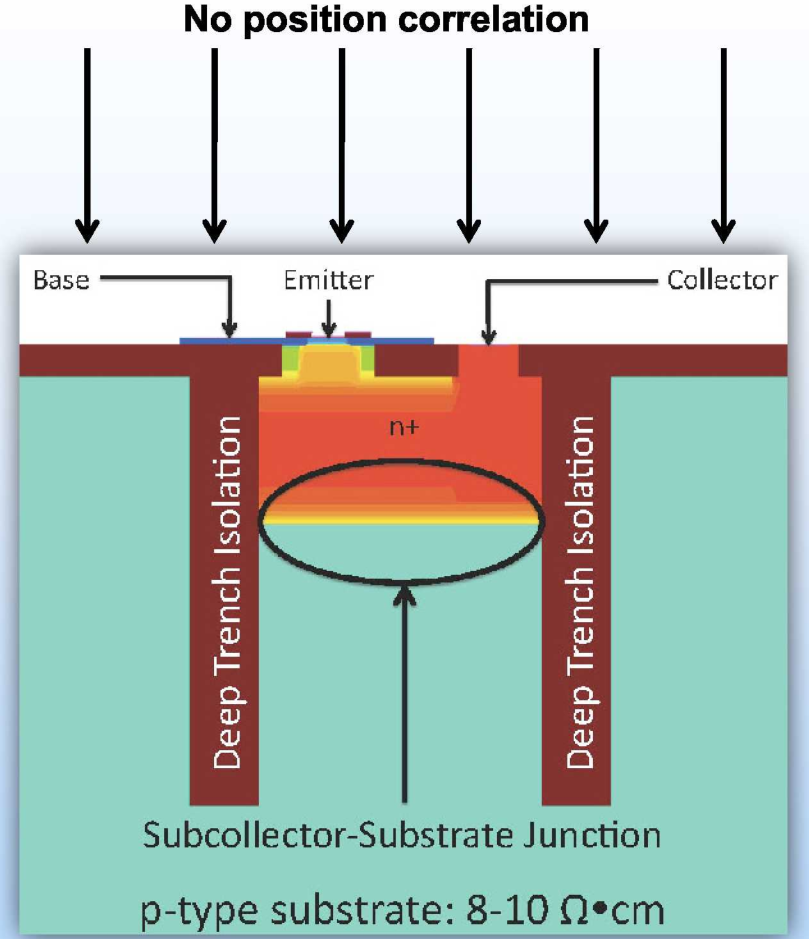
Both data sets for CASE 1 (V_{sub} = -4 V)





Microbeam

Heavy Ion Broadbeam Transients



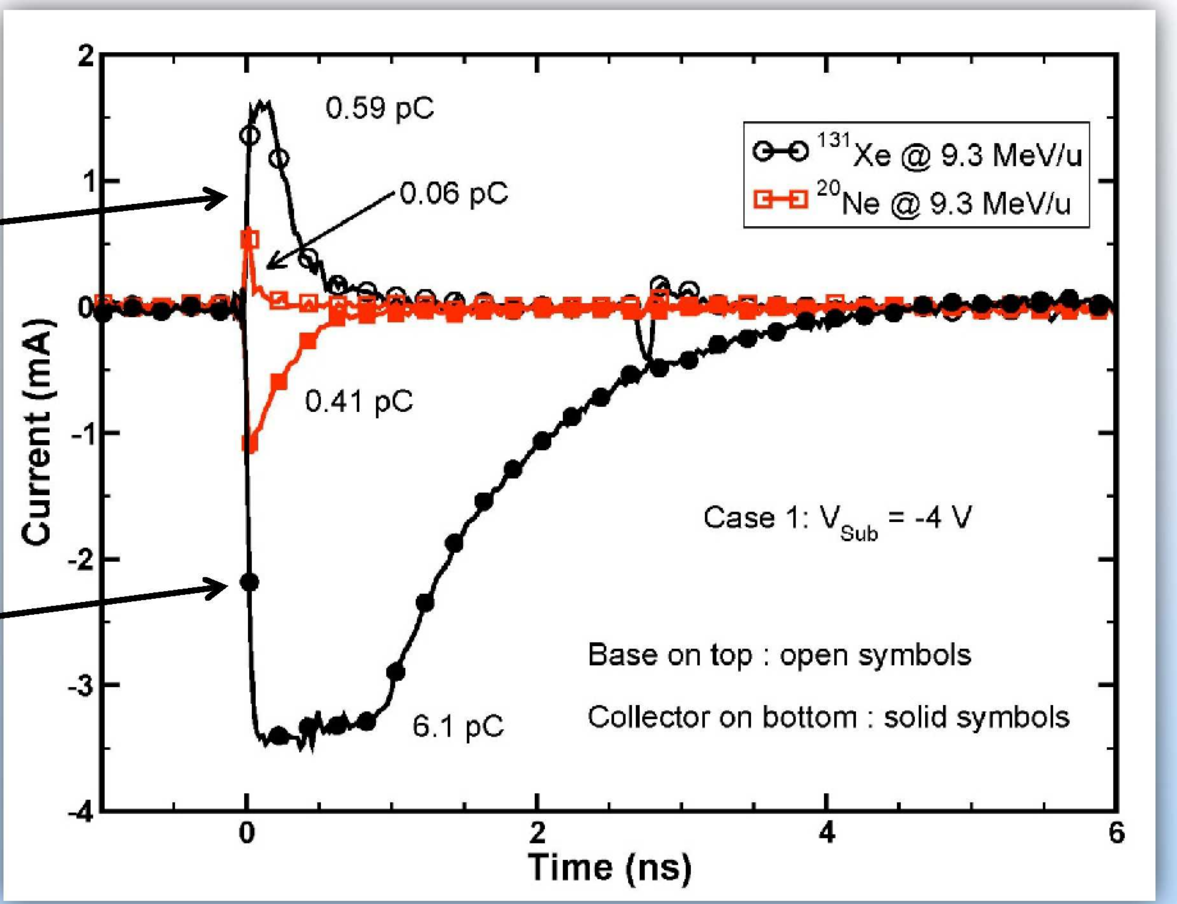
University of Jyväskylä
K-130 Cyclotron

- **Data collection at the University of Jyväskylä, Finland and GANIL, France**
- **9.3 MeV/u cocktail including ^{20}Ne, ^{40}Ar, ^{82}Kr, and ^{131}Xe and 45.5 MeV/u ^{136}Xe**

JYFL Broadbeam Transients

Base

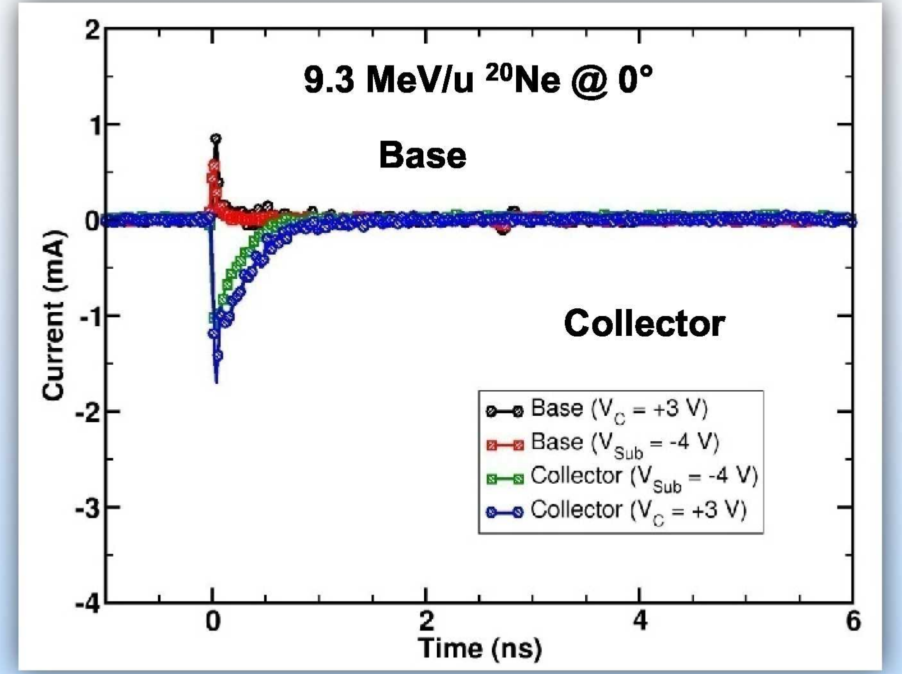
Collector

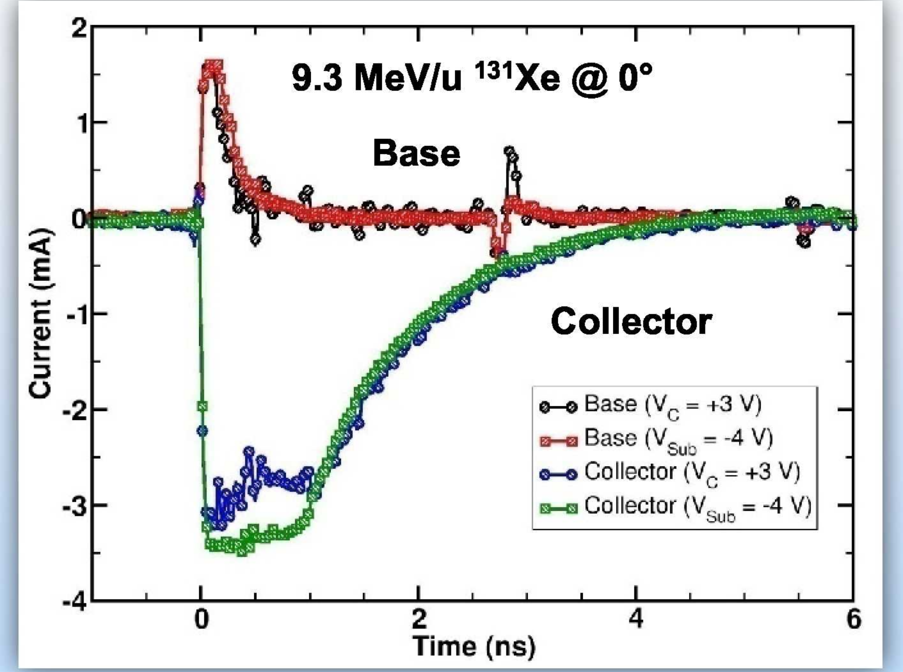


- Typical events observed from events somewhere within active region
- Position inferred using SNL microbeam data

JYFL Broadbeam Transients

Maximum amplitude transients as a function of bias

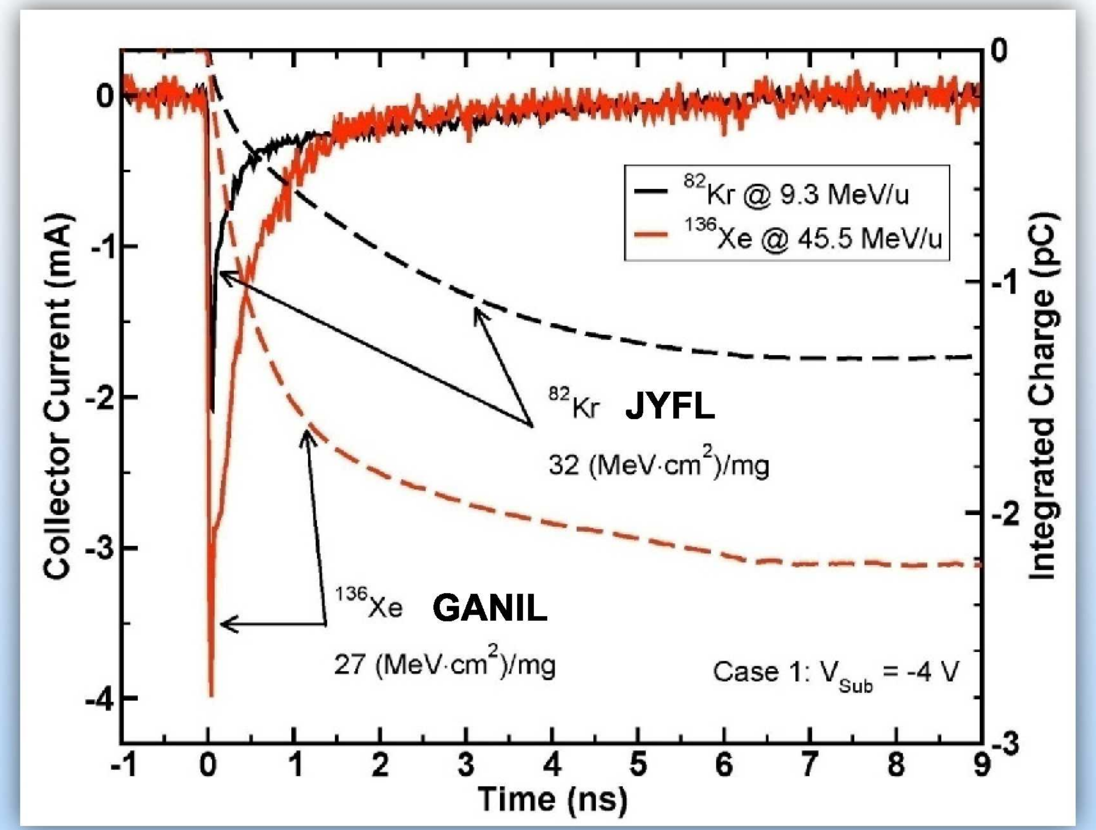




- **Saturation of collector current transient with highly ionizing particle**
- **Some bias dependence, but masked by random hit location**

JYFL *vs.* GANIL Broadbeam Transients

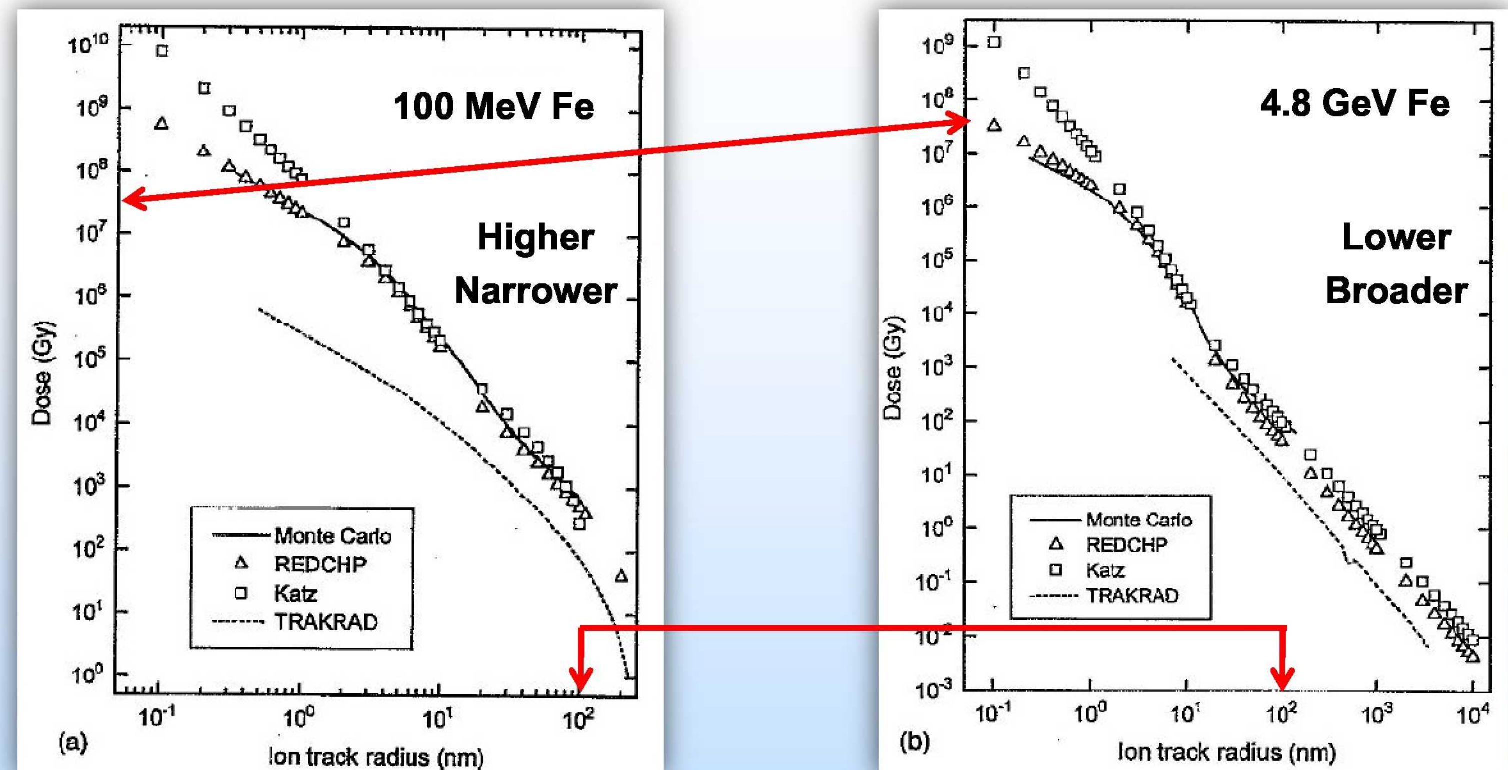
Ion Range



Recombination

- **Similar LET values produce different transient responses**
- **Trend holds for average of all transients for each LET**

Influence of Ion Energy



O. Fageeha *et al.*, *J. Appl. Phys.*, vol. 75, no. 5, p. 2317, Mar. 1994.

- **Ion energy determines *δ*-ray energy**
- **Higher energy ion reduces eh-plasma density**
  - **Ambipolar and bipolar transport affected by carrier density**
  - **Space charge screening effects**

Path Forward

- **Attempt to uncover reason for increase in collector current for V_C = +3 V bias condition**
  - **Impact ionization or other positive feedback mechanism**
- **Conduct simulation study to understand differences between microbeam and broadbeam data**
  - **Alleviates some difficulties with modeling TPA data**
- **Uncover role of ion range and recombination mechanisms in lightly-doped substrates**
  - **GANIL 45.5 MeV/u ^{136}Xe *vs*. JYFL 9.3 MeV/u ^{82}Kr**

Order of Operations

GDSII-to-TCAD → 3-D Simulations → Simulation comparison to data

Summary

- **Time-resolved ion beam induced charge reveals heavy ion response of IBM 5AM SiGe HBT**
  - Position correlation
  - Unique response for different bias schemes
  - Similarities to TPA pulsed-laser data
- **Heavy ion broadbeam transients provide more realistic device response**
  - Feedback using microbeam data
  - Overcome issues of LET and ion range with microbeam
- **Both micro- and broadbeam data sets yield valuable input for TCAD simulations**
  - Uncover detailed mechanisms for SiGe HBTs and other devices fabricated on lightly-doped substrates